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Bethesda, MD 20084–5000

DTRC–SME–CR–01–91 March 1991
Ship Materials Engineering Department
Research and Development Report

U.S. Navy Shipboard–Generated Plastic Waste Pilot Recycling Program

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CONTENTS

FIGURES

TABLES

ABBREVIATIONS

AFFF	Aqueous Film Forming Foam
ASTM	American Society for Testing and Materials
CNET	Chief of Naval Education and Training
CSWS	The Council for Solid Waste Solutions
DTRC	David Taylor Research Center
FDOT	Florida Department of Transportation
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
MARPOL	International Convention for the Prevention of Pollution from Ships
MRF	Materials Recovery Facility
MWR	Morale, Recreation and Welfare
NWT	National Waste Technologies, Inc.
PET	Polyethylene Terephthalate
PVC	Polyvinyl Chloride
SPI	The Society of the Plastics Industry, Inc.

DEFINITIONS

commingled plastic—a mixture of plastics, the components of which may have widely differing properties.

industrial plastic scrap—material originating from a variety of in-plant operations that may consist of a single material or a blend of materials.

recovered material—materials and by-products that have been recovered or diverted from solid waste, but not including those materials and by-products generated from, and commonly reused within, an original manufacturing process.

recycled plastic—those plastics composed of post-consumer material or recovered material only, or both.

plastic recycling—a process by which plastic materials that would otherwise become solid waste are collected, separated, or processed and returned to use.

post-consumer materials—those products generated by a business or consumer that have served their intended end uses, and that have been separated or diverted from solid waste for the purpose of collection, recycling, and disposition.

Reference ASTM D-5033-90 "The Development Standards Relating to the Proper Use of Recycled Plastics."

Note: The Coast Guard, responsible for enforcing the United States enactment of MARPOL, defines plastic as: "... any garbage that is solid material, that contains as an essential ingredient one or more synthetic organic high polymers, and that is formed or shaped either during the manufacture of the polymer or polymers into a finished product by heat or pressure or both. [Degradable plastics, which are composed of combinations of degradable starches and are either (a) synthetically produced or (b) naturally produced but harvested for use, are included in this definition.]

Reference Section 151.6 of 35986 Federal Register, Vol. 55, No 171, September 4, 1990.

U.S. Navy Shipboard-Generated Plastic Waste Pilot Recycling Program

Executive Summary

From April 1990 through January 1991, the David Taylor Research Center undertook a joint pilot program with The Council for Solid Waste Solutions (CSWS) to explore the feasibility of recycling Navy shipboard-generated plastic wastes. Plastic wastes are source separated aboard Navy ships and retained for shoreside disposal in accordance with new fleet requirements implementing MARPOL Annex V that prohibits the discharge of plastics at sea.

The objectives of the pilot program were (1) to determine the feasibility of creating a "recycling loop" for shipboard-generated plastic wastes—from shipboard collection and storage, to processing and remanufacture of the Navy's plastic waste materials into recycled plastic end products that in turn could be used by the Navy; (2) to determine the suitability of Navy shipboard-generated plastic wastes for future recovery Navy-wide; and (3) to identify any special requirements for handling, sorting, and cleaning shipboard-generated plastic waste prior to processing into recycled products.

The Navy supplied more than 25,000 pounds of plastic wastes from USS *Lexington* (AVT 16) and ships from the Norfolk Naval Base to three manufacturers selected by CSWS on the basis of unique processing capabilities or requirements for the incoming waste. Hammer's Plastic Recycling Corp. of Iowa Falls, Iowa, has produced recycled plastic lumber from industrial and post-consumer plastic since 1984 and is currently an industry leader in marketing recycled plastic lumber products such as park benches, picnic tables, plastic lumber and carstops. Rivenite Corporation of Philadelphia, Pennsylvania, (formerly Riverhead Milling, Inc.) uses innovative processing technology that blends mixed plastic wastes with sawdust to produce a plastic lumber product (Rivenite®) that closely resembles wood in texture and appearance because it contains approximately 50% wood fiber. National Waste Technologies, Inc., of Ronkonkoma, New York, was selected based on the firm's use of the widely publicized, commercially available ET-1 extrusion technology that recycles 100 percent commingled post-consumer plastic in a fully automated system.

From November 1990 through January 1991, 23,800 pounds of shipboard-generated plastic waste, consisting of films and flexible packaging, stretch wrap, 5- and 55-gallon containers and a variety of

mixed plastic waste, was recovered for recycling. Collectively, the three manufacturers produced 20 picnic tables, 134 park benches and 32 carstops that are now being installed at Navy stations around the country to promote Navy plastic recycling programs.

The Navy shipboard generated plastics collected for the pilot program were sorted before they were recycled because Navy plastic waste, collected in accordance with the MARPOL Annex V definition of plastic, contains large quantities of composite plastic items that are not easily recyclable (e.g., plastic-backed paper and molded plastic parts with metal pieces). Recycling food-contaminated plastics may not be practical without a suitable storage, handling and transportation system that overcomes the serious sanitation problems associated with handling this type of waste.

Navy ships generate high-value plastic wastes in the form of high-density polyethylene (HDPE) plastic containers and low-density polyethylene (LDPE) packaging films. If these materials are separated by type and color and stored away from excessive moisture and dirt, they can command a premium price on the recycled resin market and will be suitable for higher-value uses in addition to plastic lumber. Notwithstanding this, if the plastics remain in a commingled state, they have value in manufacture of plastic lumber items which can be procured by the Navy. This study suggests that if Navy ships separate food-contaminated wastes from other plastic wastes at sea, any additional sorting of the waste stream can be accomplished by a shoreside facility, such as a materials recovery facility (MRF) or sorting line at the plastic recycling manufacturer. These sorting options parallel those currently conducted by facilities handling household recyclables generated by communities across the country.

Education, feedback, and command support for shipboard recycling programs are essential for maximizing crew participation and minimizing contamination of the waste stream with non-plastic items. Use of specially marked "plastics only" containers increases the convenience and effectiveness of plastics collection for compliance with fleet directives and supports the plastic recycling program.

In light of the rapid growth of the plastic recycling industry nationwide, the pilot program demonstrated that the outlook for recycling Navy shipboard-generated plastic wastes is very optimistic.

INTRODUCTION

In April 1990, the David Taylor Research Center and The Council for Solid Waste Solutions agreed to undertake a joint pilot program to explore various methods for recycling Navy shipboard-generated plastic wastes and to identify uses within the Navy system for

finished products made from recycled plastics. The pilot program had three objectives:

- to determine the feasibility of taking Navy plastic waste through the entire "recycling loop," from shipboard collection to remanufacture of the Navy's plastic waste materials into recycled products that the Navy could use;
- to determine the suitability of Navy shipboard-generated plastic wastes for future recovery Navy-wide; and
- to identify any special requirements for handling, sorting, and cleaning of plastic waste material prior to processing into recycled products.

This report documents the results of the pilot program and recommends future action to recover Navy plastics.

Administrative Information

This report describes work performed by The Council for Solid Waste Solutions, Washington, DC, in a joint research project (N61533-90-M-0588) with the Environmental Protection Branch of the Chemical and Physical Processes Division, Ships Materials Engineering Department, David Taylor Research Center (DTRC), Annapolis Laboratory. The Navy program manager for this project was Mr. Arthur Smookler, Advanced Ship Concepts Development Subgroup of the Ship Concepts Development Group, Naval Sea Systems Command (SEA 51126) under program element No. 63721N, Project No. S0401-SL001, work unit no. 1-2934-141. This report is co-authored by David Taylor Research Center, The Council for Solid Waste Solutions and R.W. Beck of Orlando, FL (under contract to The Council for Solid Waste Solutions).

Acknowledgments

We thank the following people for their support, suggestions, and cooperation during the conduct of this unique recycling venture: the officers and crew of *Lexington* (especially CAPT C. Flack Logan, CAPT R. Penfold, CDR Rick Arllen, and LT Charlotte O'Brien); J. J. Hoyt (Norfolk Naval Base Recycling Coordinator); Charlie Miller (Escambia County, Division of Solid Waste); David Jones (Pensacola Waste Paper, Inc.); Damon Boyle (Waste Reduction Systems); Kevin Brown (National Waste Technologies, Inc.); Roger Wittenberg and Larry Umstadter (Rivenite Corporation); Floyd Hammer and Brian

Harper (Hammer's Plastic Recycling Corp.); and Drew Jackson and Linda Copeland of the David Taylor Research Center, Annapolis Laboratory.

BACKGROUND

Since January 1989, U.S. Navy ships have been retaining most of their plastic waste for disposal ashore in accordance with new Navy policy. This policy is a result of The Marine Plastic Pollution Research and Control Act of 1989 (which implements Annex V of the International Convention for the Prevention of Pollution from Ships, or MARPOL). This legislation, which bans the disposal of plastics into the ocean, resulted from international and national pressures to halt the flow of synthetic materials into the ocean and thereby reduce the potential for entanglement, ingestion, and death to marine life and to stem the rising tide of debris on shorelines around the world. The Navy has been given until 1994 to comply fully and has responded by implementing strict source separation and storage of plastic wastes shipboard.

In March 1988, Chief of Naval Operations tasked David Taylor Research Center (DTRC) to conduct shipboard plastic waste management demonstrations in cooperation with Commander in Chief, U.S. Atlantic Fleet; Commander in Chief, U.S. Pacific Fleet; Commander Naval Sea Systems Command; and Commander Naval Supply Systems Command. The objective was to demonstrate, document, and evaluate operational, supply and technology-oriented solutions to reduce plastic waste discharges at sea, manage the total solid waste stream, and measure the resulting impact on resources. Engineers and scientists from DTRC collected waste generation rate and characterization data and monitored and documented lessons learned on eight Navy ships. In addition to evaluating shipboard source separation procedures, DTRC demonstrated technologies including the Navy-developed trash compactor, a shipboard solid waste pulper for processing non-plastic waste, and odor barrier bags for long-term storage of food-contaminated plastics. The last demonstration ship, USS *Lexington* (AVT 16), successfully demonstrated proof of the Navy's solid waste management concept, vital to the Navy's goal of an environmentally-compliant ship.

As a result of experience gained during the demonstration studies, the Fleet Commanders of the Atlantic and Pacific Fleets issued policy guidance to commanding officers of their ships. Ships are required to retain nonfood-contaminated plastic waste for at least the first 20 days of all underway periods, and longer if space and safety considerations allow. Plastic that is contaminated with food waste must be held on board for the last 3 days of any underway period.

Often, a ship is underway for a short period and no plastic waste need be discharged overboard. Fleet implementation of the new procedures has produced an immediate 70% reduction in the total plastic waste discharged. Yet these reductions have only been achieved by sacrificing quality of life aboard Navy ships. Navy ships have virtually no extra storage space for plastic wastes forcing sailors into creative solutions to comply with the new requirements. Storage of large quantities of plastic wastes introduces potential hazards due to the combustibility of plastics and resulting toxic fumes. Also, storage of food-contaminated plastics cause odor and sanitation problems.

These operational changes afford the Navy's engineering community time to develop and install solid waste management equipment aboard ships that will promote still further reductions. Sponsored by the Naval Sea Systems Command, DTRC is developing a shipboard plastic waste processor that will densify all plastic waste into sanitized, brick-shaped blocks that can be easily stored on a ship until it returns to port, solving the odor and sanitation problems associated with handling food-contaminated plastic waste. In the meantime, plastic waste stored by Navy ships while at sea is disposed of ashore, joining the rest of the shipboard solid waste stream in pierside collection containers.

Plastics are found in large quantities on Navy ships. Virtually every ship activity requires use of some plastic product. A few of the obvious uses include: food packaging and disposable eating utensils; products for personal hygiene; protective packaging; ship construction (fiberglass and laminated structures, piping insulation, flooring, carpets, fabrics, adhesives, and electrical and electronic components); shrink wrap and strapping bands; hardhats and clothing; and synthetic ropes and lines. Based on the shipboard studies conducted by DTRC, the Navy estimates that its ships generate plastic waste at 0.1 to 0.2 pounds per person per day. While this figure seems relatively small, it is comparable to the national plastic waste generation average of 0.36 pounds per person per day. Accordingly, Navy plastic waste represents a potentially large source of recyclable material.

Recognizing the need to reduce the impact of shipboard-generated plastic waste at naval facilities and the local municipal landfills serving them, the Navy contacted The Council for Solid Waste Solutions (CSWS) for assistance in evaluating the potential of recycling Navy shipboard-generated plastics. The Council for Solid Waste Solutions is a Washington-based task force, and a program of The Society for the Plastics Industry, Inc. Its goals are to help develop a national infrastructure for plastics recycling and to promote viable markets for the recovery of post-consumer plastics. CSWS actively supports pilot plastic recycling projects and provides technical assistance in plastic recycling to municipalities across the United States. In

this capacity, CSWS is uniquely qualified to help the Navy actively address the increase in shoreside solid wastes resulting from the new Navy initiatives.

Since its inception in 1988, CSWS has been the point of contact for plastics recycling development for both industry and government concerns in collection, handling, reclamation, and end-use markets across the country. The major focus has been on post-consumer plastics—those plastic products that have served their intended end use and are headed for disposal. Disposable containers, such as glass bottles and aluminum cans, were among the original materials separated during early recycling attempts in the 1970s. Plastic containers are now becoming an important part of recycling programs growing rapidly across the country.

The plastics industry is accelerating the rate of recycling plastics as part of its commitment to develop solutions to solid waste management problems. For example, 28% of soft drink bottles made of polyethylene terephthalate (PET) are being recycled and it is projected that 50% of all PET containers will be recycled by 1993. Aggressive recycling programs are being disclosed by industry leaders. DuPont has joined with Waste Management to form the Plastics Recycling Alliance that recycles post-consumer bottles; Oxychem buys all polyvinyl chloride (PVC) bottles in minimum 5000-pound quantities; and Union Carbide is building a plant in New Jersey to recycle both bottles and film plastic waste. A study done by CSWS has produced a database of 610 handlers of plastics and 274 reclaimers nationally. In addition, a number of companies are reclaiming commingled (mixed) plastics for manufacture into plastic lumber products. More than 500 communities across the country have documented plastics recycling programs, although more current estimates and growth projections bring that number much higher. Development of new equipment for collection, handling, and reclamation is continuing apace.

To summarize, plastics recycling is undergoing a great period of growth in this country, providing opportunities for both municipalities and specific user communities such as the Navy.

Navy activities have not been immune to the growing national mandate to recycle because their activities also are faced with rising waste disposal costs and diminishing landfill space. Navy activities have for some years been recycling scrap metal, aluminum cans, office paper and cardboard through qualified recycling programs. More recently, bases have been adding household plastics collected in drop-offs and curbside programs to the recycling programs. The proceeds from the sale of most recyclables are returned to the base or activity. Once costs for implementing the recycling program are recovered, the base commander may then allocate from 50 to 100 percent of the proceeds to Morale, Recreation and Welfare (MWR)

activities (such as recreation facilities, snack bars, fitness centers, etc.). Remaining funds can be used to support environmental, safety, or energy programs. At the onset of this program, there were no known Navy ships targeting their plastic wastes for recycling. Thus, CSWS agreed to participate in a joint effort with the Navy's David Taylor Research Center, Annapolis Laboratory, to investigate the potential for recycling the Navy's shipboard-generated plastic waste stream.

Under the terms of the agreement, the Navy was to provide up to 20 tons of Navy shipboard plastic waste and provide all shipping and handling costs for the pilot program. CSWS agreed to work with one or more plastic recycling companies to establish the feasibility of recycling the wastes. The Navy selected end-products that could be used for promotional purposes at the Navy bases where the wastes originated and that could potentially be procured for use by the Navy. CSWS agreed to provide parking lot carstops, picnic tables, and park benches with plaques attached stating the shipboard origin of the recycled material. CSWS retained R.W. Beck & Associates, a recycling and solid waste consulting firm, to coordinate the day-to-day activities between all parties involved. Documentation and technical analysis of the successes and problems encountered in the program would also be provided.

Approach

The Navy nominated *Lexington*, the Navy's training aircraft carrier homeported in Pensacola, Florida, to be the demonstration ship for the pilot program because of the ship's previous involvement with DTRC in afloat solid waste management studies. DTRC requested *Lexington* to collect and store all shipboard-generated plastic wastes during four at-sea periods (from April through August 1990) and while docked in port. Arrangements were made to place a special dumpster pierside to collect *Lexington*'s plastics after off-loading. Plans were made to transport the materials to a local paper recycling company, Pensacola Waste Paper, Inc., for baling and shipment to selected plastic recyclers for manufacture into recycled plastic products. DTRC and CSWS intended to document each step of the recycling loop and to obtain feedback from the recyclers on the quality of the waste material to help assess feasibility of Navy-wide shipboard-generated plastic waste recycling.

Although the Navy initially estimated that *Lexington* could collect 20,000 pounds of food-contaminated and nonfood-contaminated waste during the program, it became evident mid-way that this goal could not be achieved because of source separation problems and the complicated logistics of handling food-contaminated wastes. In or-

der to obtain sufficient quantities of processible plastic for the pilot program, DTRC contacted the Norfolk Naval Base to arrange for additional shipboard-generated plastic wastes. Norfolk Naval Base recovers recyclables from shipboard-generated solid wastes at its Transfer Station, and when requested, the Norfolk Naval Base Recycling Coordinator added plastics to the list of recoverables to support this program.

Materials collected from *Lexington* and the Norfolk fleet were shipped to three plastic lumber manufacturers selected by CSWS to process the Navy's shipboard-generated plastics into end products. Each firm selected had special requirements for the incoming waste stream or specialized techniques for processing the waste. By conducting the pilot program with several manufacturers, CSWS was able to assess feasibility from several different viewpoints, especially important in this rapidly evolving industry. Descriptions of the three manufacturers follow.

Hammer's Plastic Recycling Corp.

Hammer's Plastic Recycling Corp. (Hammer's) of Iowa Falls, Iowa, was selected by CSWS based on the firm's reputation as an industry leader in marketing recycled plastic lumber products. Hammer's has produced recycled plastic lumber from industrial and post-consumer plastic materials since 1984. The company began manufacturing a variety of recycled plastic agricultural products including grating, molded equipment stands, and fencing. Hammer's primary product line now includes plastic park benches, picnic tables, lumber, and carstops. Of special interest for marine applications, Hammer's also markets a line of plastic marine pilings that are 13-inch in diameter and up to 60 feet in length. These pilings consist of a recycled plastic exterior extruded over a 5-inch steel core.

The extrusion process converts the plastic into a continuous molten stream and forces the material through a die into a mold creating a uniform cross sectional shape or "profile." This process allows for the production of finished products with virtually unlimited combinations of size and shape. Hammer's patented recycled plastic extrusion technology produces molded plastic lumber profiles up to 16 feet long. In addition to extruding profiles, Hammer's facility is capable of molding plastic piece parts, such as end-pieces for park benches and the special purpose agricultural products. Hammer's typically processes 15% industrial, low-density polyethylene (LDPE) scrap along with household plastic waste (which consists primarily of high density polyethylene (HDPE)

milk jugs and water bottles) to improve surface finish of the extruded profile. Under normal conditions, approximately five to six ground plastic resin types are used to produce end-products. Color concentrate can be added at about 4% by weight to provide color consistency.

A modified shredder grinds oversized plastic waste products (such as large-mouth containers) into small chips for the extruder (see Figure 1). Industrial scrap, which arrives in the form of flakes or pellets, is weighed and mixed with the ground materials to obtain an appropriate blend. This blend is fed from the extruder hopper to the extruder where it is heated in excess of 300° F. Molten plastic from the extruder fills the profile molds. These stand for several minutes to allow flow stresses to be relieved before cooling in a water bath. Once the profile or produ ·· is hardened, the mold is opened and the profile extracted, either by hand or pneumatically. Figure 2 shows several loads of plastic lumber awaiting shipment or preparation for end-product assembly.

Hammer's maintains strict quality standards for plastic materials used to produce the firm's plastic lumber products in order to maintain control over the quality of the outgoing product. The use of relatively high percentages of industrial scrap of known resin type helps produce this high level of quality assurance. In addition to industrial scrap, Hammer's processes mostly sorted, post-consumer, plastic containers.

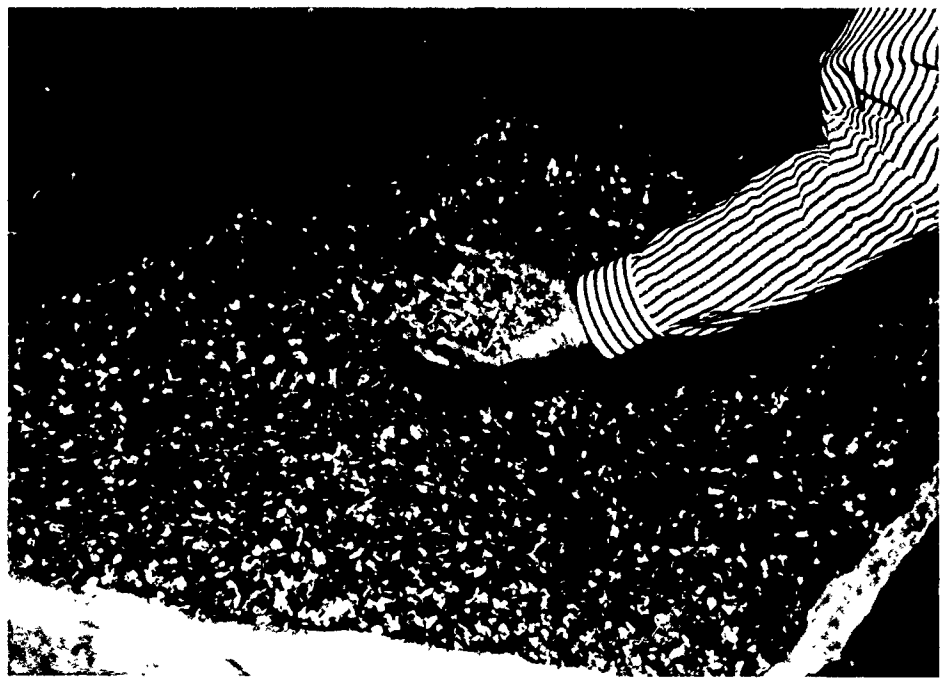

Figure 1: Hammer's Plastic Recycling Corp.— gaylord of ground HDPE

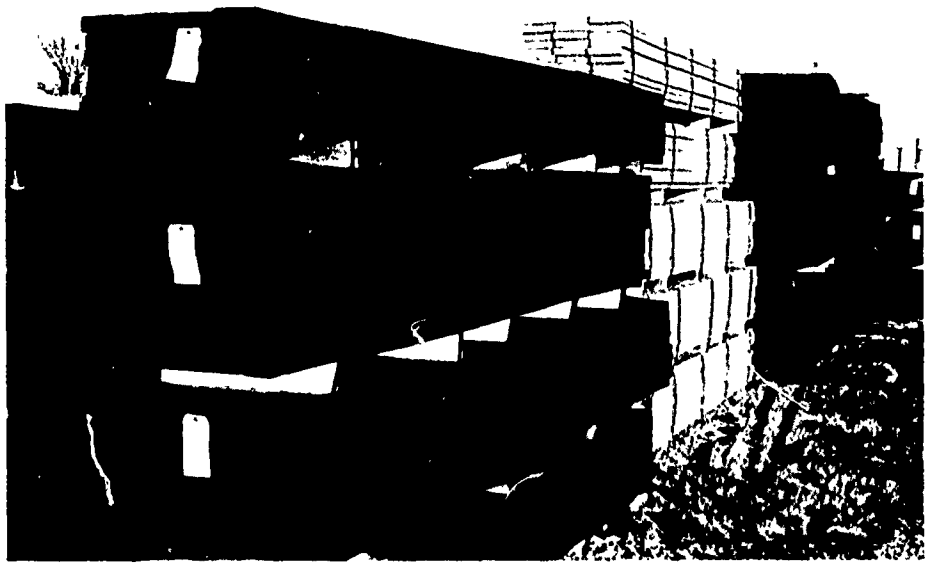

Figure 2: Hammer's Plastic Recycling Corp.— plastic lumber awaiting shipment

Food-contaminated plastics and composite plastic products that would be found in a municipal solid waste stream are explicitly rejected. Materials accepted for processing by Hammer's must also be fairly clean and dry.

This type of process does not tolerate excessive moisture because the water expands as it turns into steam, when heated by the extrusion process. This produces large cavities in the plastic lumber, which in turn reduces the tensile and compressive strength and rigidity of the lumber product. Although Hammer's process requires that incoming plastic waste contains no more than 0.2% moisture content by weight, this is generally assessed visually. Hammer's operation has no internal standards for demoisturizing incoming wastes or equipment to measure an acceptable level of moisture. Often this problem takes care of itself, since small amounts of moisture are removed from the plastic wastes by the local heat created during the grinding procedure. A modest amount of dirt also is acceptable since fine, particulate contaminants move to the center of the plastic profile during the mold-filling process. Limited quantities do not adversely affect the structural soundness of the end-product. Similarly, Hammer's process tolerates small pieces of paper, aluminum and other small contaminants.

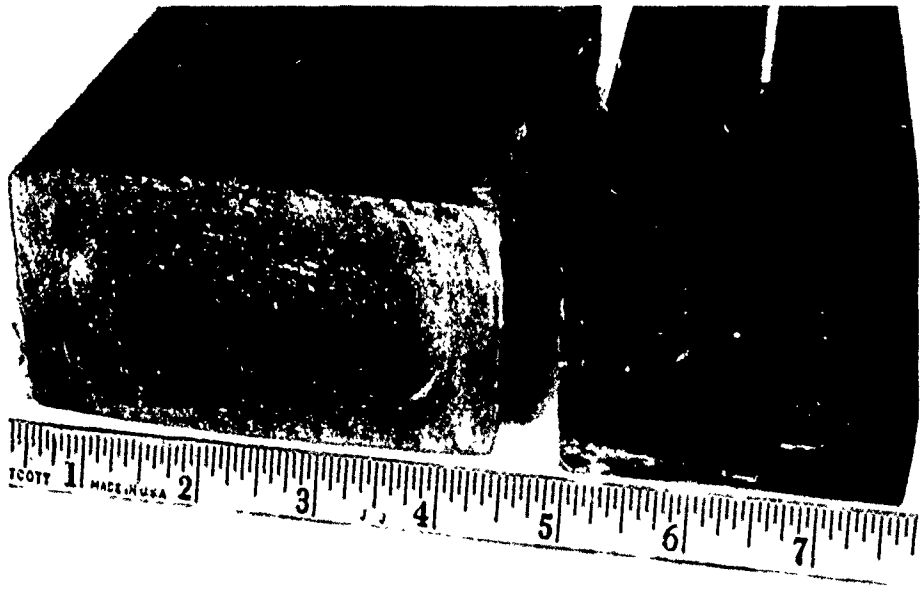

Figure 3: Cross-section view of Rivenite® (left) and 100% recycled lumber

Rivenite Corporation

Rivenite Corporation (Rivenite), formerly Riverhead Milling, Inc., of Philadelphia, Pennsylvania, was selected for the pilot program based on the firm's innovative and unique processing technology that blends mixed plastic waste with sawdust to produce a plastic lumber product called Rivenite®. Rivenite® more closely resembles wood in texture and appearance than 100% recycled plastic lumber because it consists of approximately 50% wood and is free of the air cavities and voids often found in recycled plastic lumber. Figure 3 shows a comparison of cross sections of each. The manufacturer claims this results in improved tensile strength.

Another reason for selecting Rivenite as a participating manufacturer was that Rivenite's process tolerates certain types of contamination, including some types of food. Although Rivenite maintains relatively high plastic feedstock quality requirements, Rivenite also routinely processes large quantities of bakery food packaging (such as bread and pastry wrappers) and landscape products bags (such as peat-moss bags), both with substantial residues still inside. We thought the Rivenite process might answer one major ques-

tion raised at the start of the pilot program: "Can the Navy recycle the food-contaminated plastic wastes generated shipboard?"

Rivenite's primary products include plastic picnic tables, carstops, and industrial flooring. Rivenite® fence posts recently underwent long-term, environmental testing in a program conducted by the State of Florida Department of Transportation (FDOT). This test, which will be used to select alternative materials for highway right-of-way fencing, focused on evaluating capability to remain plumb and true in the extremely warm Florida summer temperatures. According to the manufacturer, Rivenite® was the only product of twelve tested to receive an unconditional approval from FDOT.

Unlike most other manufacturers that process recycled plastic lumber in batches, Rivenite's technology is capable of performing continuous extrusion of Rivenite®. This increases throughput of the facility significantly and thereby reduces the average production cost of the material.

Although Rivenite can process "hard" plastic wastes such as milk jugs and other rigid containers, the primary waste feed consists of LDPE films such as garbage bags, sheet plastic, and bubble-wrap. First, waste plastic film from food and beverage distributors is debaled and manually fed into a

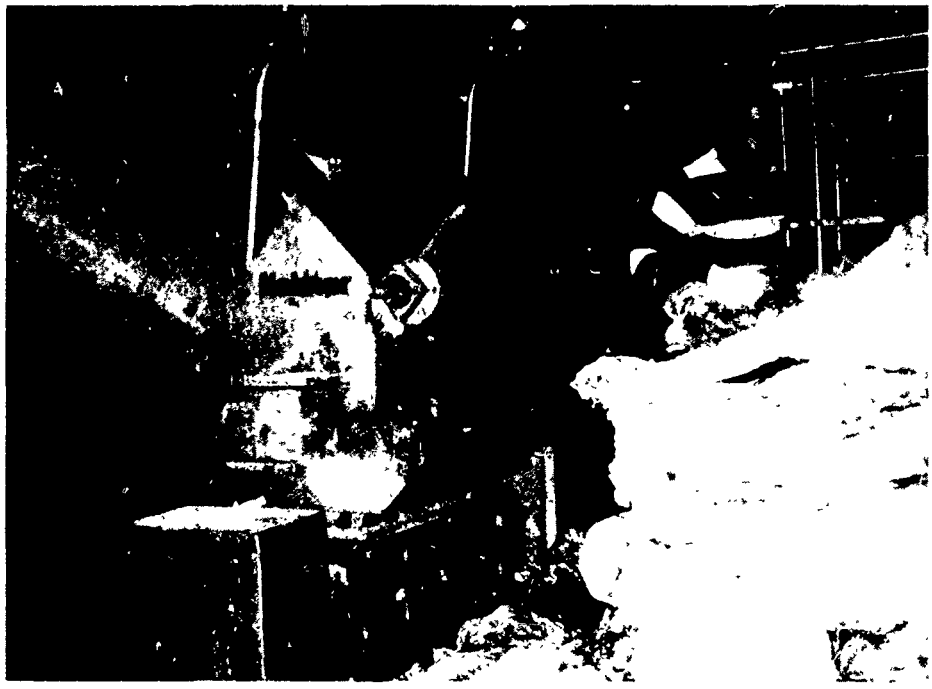

Figure 4: Rivenite Corporation—grinding LDPE film plastics

scissors-action grinder equipped with film blades (shown in Figure 4) and the ground film is vacuum fed into a storage hopper. This feed plastic is then automatically weighed and mixed with a similar quantity of sawdust. Rivenite uses a microprocessor system that accurately mixes appropriate quantities of each material depending upon the type and density of the incoming materials.

Next, the mixed material is fed into a dehydration system which removes excess moisture in the sawdust or the ground plastic to reduce the potential for air cavities in the end-product. The dehydrated, mixed material is then fed into a high sheer/high temperature mixer to ensure a sufficiently homogeneous blend between the molten plastic and sawdust components. The blended material is fed via an auger feed system (shown in Figure 5) into Rivenite's proprietary con-

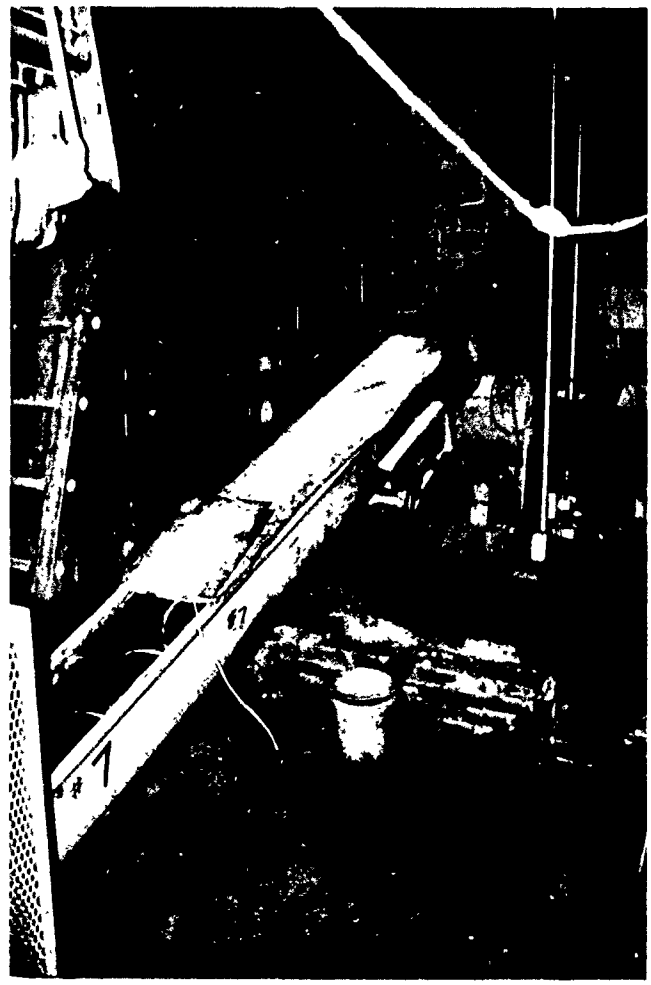

Figure 5: Rivenite Corporation—auger feed system carrying blended plastic and sawdust

tinuous extrusion system. The materials are forced through the extruder die at a minimum of 18,000 pounds per square inch of pressure. The shape of plastic lumber produced (round, square, or oblong) depends on the mold used at the end of the extrusion chamber.

Upon exiting the extruder, the continuous cast plastic profile is pulled through a cold water immersion bath for approximately 100 feet. Finally, the extruded plastic lumber is cut in product specific lengths and stacked on racks for final cooling and hardening (see Figure 6). The profiles are now ready for assembly into end-products.

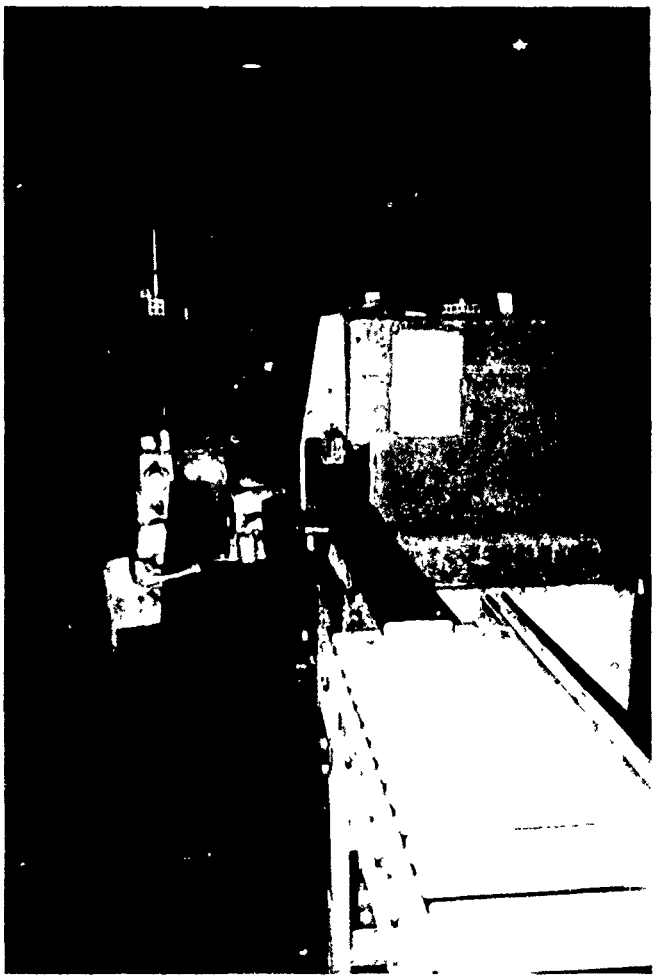

Figure 6: Rivenite Corporation—
continuous extrusion plastic lumber profile

National Waste Technologies, Inc.

National Waste Technologies, Inc. (NWT) of Ronkonkoma, New York, was selected based on the firm's use of the widely-publicized, commercially available ET-1 processing technology. The ET-1 technology allows NWT to recycle 100 % mixed (or commingled) plastic and/or post-consumer plastic in a fully automated, emission-free system. In addition, since NWT manually sorts the waste stream at the front end to separate out gross contaminants, their plastic feedstock quality requirements are quite forgiving. NWT will accept up to about 10% paper contamination. At the onset of the program, NWT stated that many non-plastic and composite plastic products would be acceptable. Since the Navy knew from the start that these items comprised some percentage of the shipboard plastic waste stream, it was of special interest to determine if these items could be processed by a recycler.

The ET-1 technology is patented by Advanced Recycling Technology SA of Belgium and to which NWT has exclusive territorial rights in the northeast region of the United States. Like the other two processes, it is basically an extrusion system that transforms plastic scrap from the waste stream into a synthetic plastic lumber product.

NWT obtains almost all its plastic wastes from local household collection programs at no cost. NWT separates these materials into distinct fractions of film and rigids and preprocesses each separately. Incoming waste is loaded onto a conveyor system (shown in Figure 7) where workers manually remove all film plastics and any items of gross contamination. The remaining plastics are shredded into strips 6 inches long and 1.5 inches wide to facilitate the removal of ferrous metal contaminants by a magnetic head separation system at the next station on the conveyor. Then, the shredded plastic is ground into 1/2 inch chips and vacuumed automatically into a silo for storage before it is mixed for processing.

Film plastic removed from the conveyor system is densified separately. Densification reduces the size and densifies the material so that it can be easily mixed with the other ground plastics and fed into the extrusion system. The densifier shreds, melts, and dries the plastic film, producing irregular, wormlike pieces less than 0.5 inch in size. Figure 8 shows samples of densified film plastic and ground HDPE. These are mixed together in the vertical auger/blender shown in Figure 9. Choosing the proper proportions of this mix is something of an art, especially since the incoming waste stream is

Figure 7: National Waste Technologies, Inc.— loading incoming waste onto conveyor system

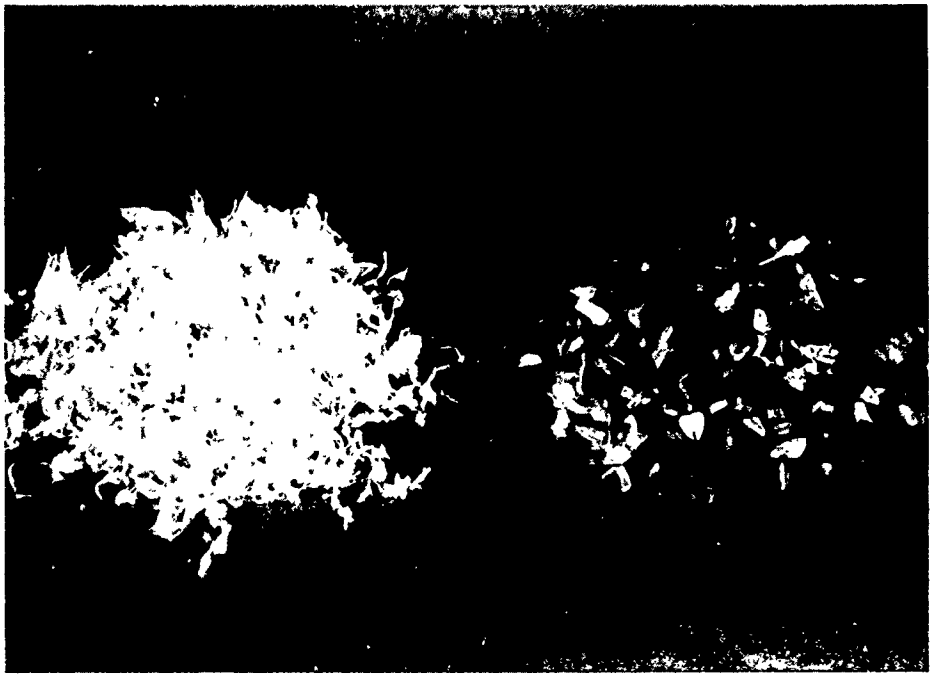

Figure 8: National Waste Technologies, Inc.— samples of densified plastic film (left) and ground HDPE

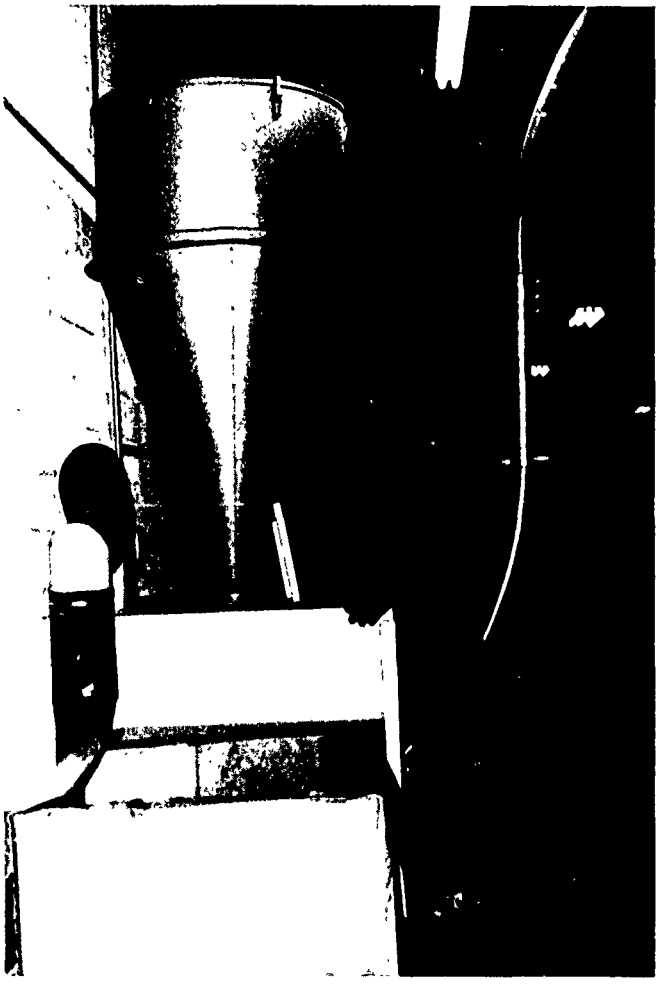

Figure 9: National Waste Technologies, Inc.—blending HDPE and densified film plastics

so varied and uncontrollable. NWT's experience is that the proportion of 79% rigid to 21% film plastic by weight from a mixed, municipal waste stream produces a good product using the ET-1 extrusion technology.

The ET-1 machine is a batch processor. The extruder fills adjacent molds on a turning carousel. Filled molds rotate down into a water cooling bath. The profiles are pneumatically ejected when cooled. Figure 10 shows the Model 9400 ET-1 extruder that can produce up to 12 foot profiles.

Figure 10: National Waste Technologies, Inc.— model 9400 ET-1 extruder

RESULTS

During November 1990 through January 1991, the three manufacturers successfully recycled 23,800 pounds of shipboard-generated plastic waste into 20 picnic tables, 134 park benches, and 32 carstops. Table 1 shows the amount, source, and type of plastic waste delivered to each manufacturer and the end-products produced for the pilot program. The following sections describe results achieved during various phases in the program.

Table 1: Plastic Waste Source, Manufacturing Destinations, and End Products

Manufacturer	*Amount (lbs)*	*Source*	*End Products*
Rivenite Corporation	7,000 film	Norfolk	20 picnic tables 32 carstops
National Waste Technologies, Inc.	10,600 rigid 1,200 mixed	Norfolk *Lexington*	87 park benches
Hammer's Plastic Recycling, Corp.	5,000 rigid	Norfolk	47 park benches
Total Processed:	23,800 lbs		

Plastic Waste Collection Aboard *Lexington*

From May through August 1990, *Lexington* collected approximately 8000 pounds of plastic waste, primarily during four at-sea periods. Of this amount, 6800 pounds were rejected and disposed of in the landfill because they were contaminated with excess food waste or non-plastic items. At the start of the pilot recycling program, *Lexington* had not yet institutionalized a shipboard plastics source separation program. As a result, plastics collected in "plastics only" shipboard containers were often contaminated with non-plastic items. Although a "plastics only" dumpster (shown in Figure 11) was placed pierside for collection of plastic wastes while in port and when returning from sea, this container also collected many obviously non-plastic items and repeatedly had to be disposed of as solid waste rather than plastic waste.

In addition, food residue on the food-contaminated plastics collected during at-sea periods had substantially decomposed by the time the plastics were collected and baled shoreside. Several attempts at short term storage of bales of *Lexington* plastic waste at Pensacola Waste Paper, Inc. resulted in insect infestations and strong odors with health and sanitation risk (see Figure 12). These wastes were ultimately landfilled. When it became apparent that collecting, storing, and transporting food-contaminated plastic wastes without specialized equipment and procedures was overly ambitious for a project of this scope, collection of food-contaminated plastic wastes was abandoned for the duration of the program and focus was shifted to non food-contaminated plastics.

Figure 11: Pierside plastic recycling container

Approximately 2000 pounds of nonfood-contaminated plastic was collected during *Lexington*'s final at-sea period of the pilot program in August 1990. At this point in the program, the plastic recycling manufacturers had requested that most non-processible materials be removed from the plastic waste before shipment. In order to accomplish this, DTRC transported this final load to the newly operational materials recovery facility (MRF) at the Escambia County Perdido Landfill. This MRF was designed for the separation and collection of recyclable materials (paper, glass, aluminum, etc.) from the unsorted municipal solid waste stream. With guidance from CSWS and DTRC representatives, employees of Waste Reduction Systems (contract operators of the MRF) removed all obvious non-recyclables from *Lexington*'s waste (see Figure 13).

Materials were sorted into four categories at the MRF: recyclable plastics, non-recyclable plastic and composite products, non-recyclable material containers, and non-recyclable non-plastic items. Items were placed in each category based on the judgment of CSWS and Navy representatives. Figure 14 shows the mixed waste stream prior to sorting. Figure 15 shows a bin of recyclable plastic materials recovered during the sort. Of the 2000 pounds of waste returned to port by *Lexington*, after sorting 800 pounds were considered

Figure 12: Lexington *plastic being baled at Pensacola Waste Paper Company, Inc.*

Figure 13: Sorting Lexington *plastic wastes at Escambia County* MRF

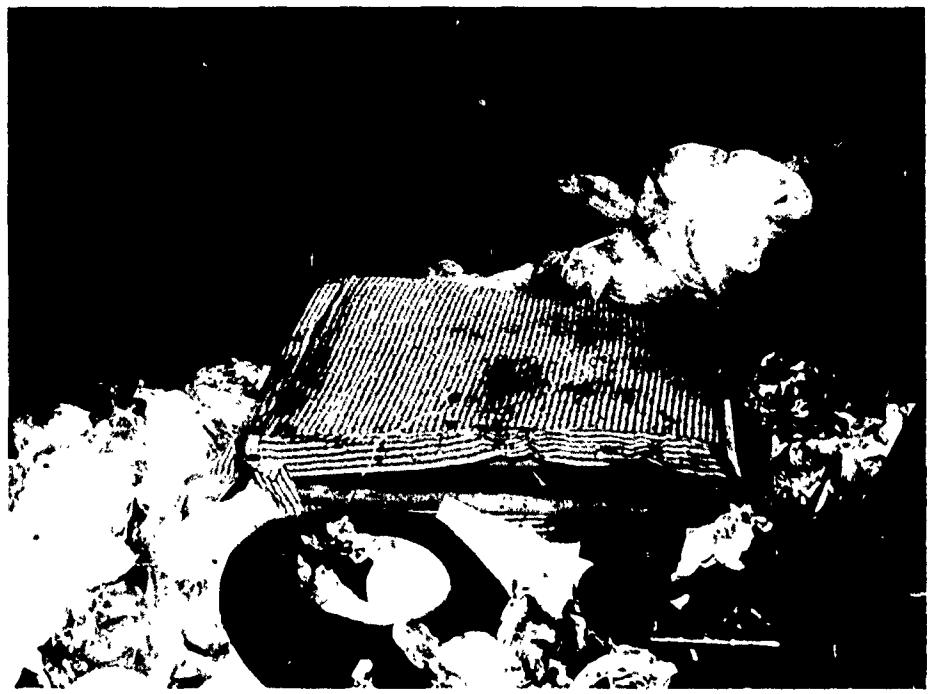

Figure 14: Materials collected aboard Lexington

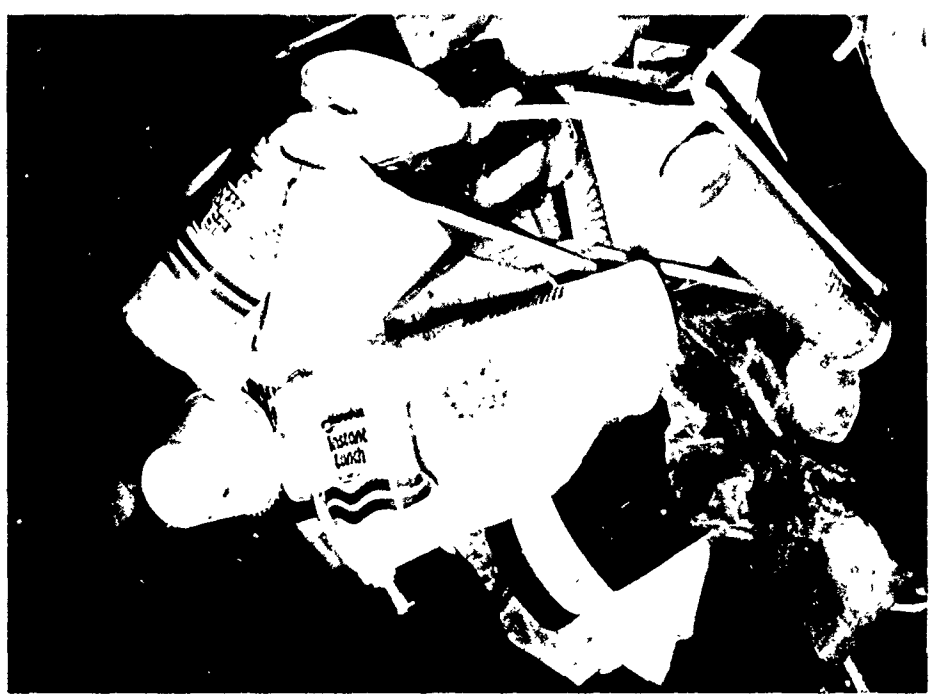

Figure 15: Recyclable materials collected aboard Lexington

"unrecyclable," even though these waste products may have been correctly stored aboard ship as a plastic item for disposal ashore. Many of these are shown in Figures 16 through 20. This fraction was disposed of in the landfill. Only 1200 pounds were deemed "recyclable." Table 2 lists the recyclable plastic items collected from *Lexington* waste at Escambia County MRF. This plastic waste was baled and shipped to National Waste Technologies, Inc..

Table 2: Recyclable Plastic Items Collected from *Lexington* Waste at Escambia County MRF

Shampoo containers
Plastic garbage bags
Tyvek suit
Shower thongs
Sponges
Cassette tapes
Polystyrene foam cups
Bread bags
Miscellaneous bottles and containers
Disposable razors
Plastic coat hangers
Empty caulk tubes
Fast food polystyrene containers
Plastic spray bottles
Plastic parts trays
Snack food wrappers and candy wrappers
Latex gloves

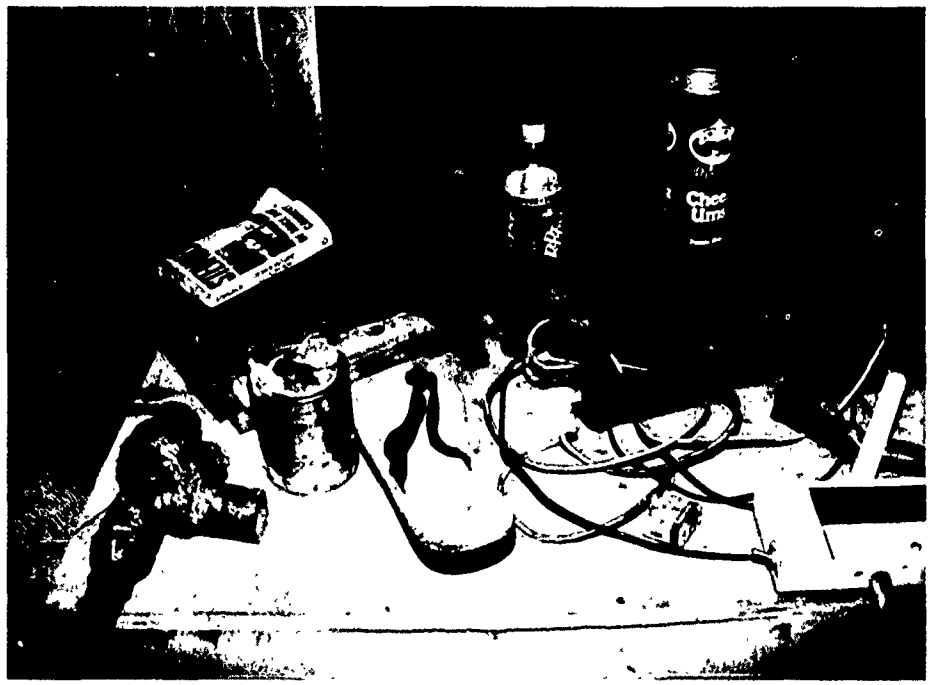

Figure 16: Examples of non-recyclable waste materials

Figure 17: Examples of non-recyclable waste materials

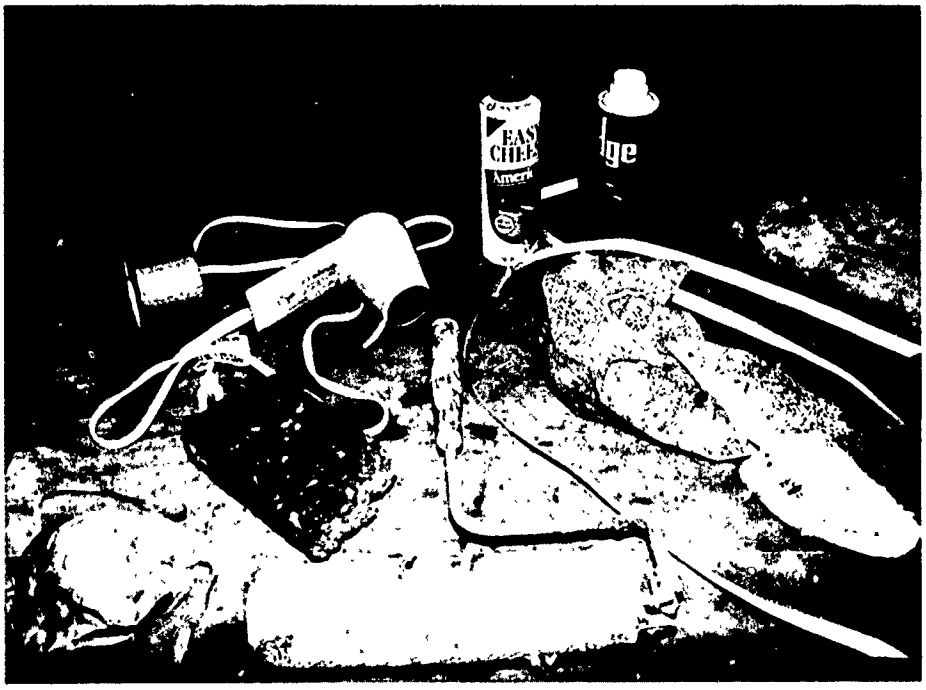

Figure 18: Examples of non-recyclable waste materials

Figure 19: Examples of non-recyclable waste materials

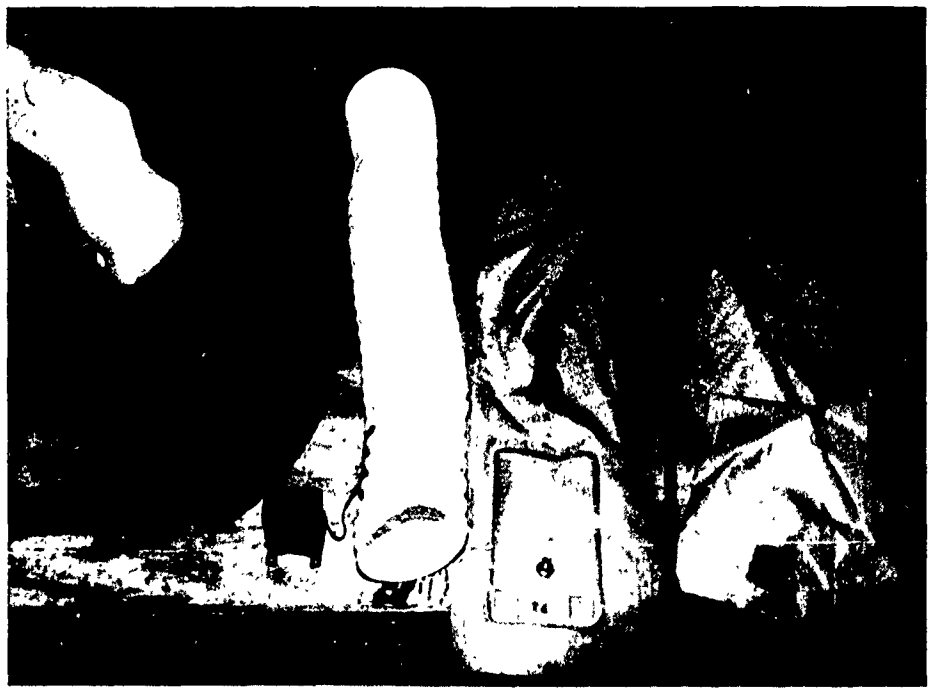

Figure 20: Examples of non-recyclable waste materials

Collection of Shipboard-Generated Plastic Waste from Norfolk Naval Base

In order to increase the quantity of shipboard-generated plastic waste, DTRC contacted the Norfolk Naval Base Recycling Coordinator in June 1990 to obtain additional plastics for the pilot program. Norfolk Naval Base has a variety of recycling programs underway, serving industrial work centers, residential areas on the base, and some pierside and shipboard activities. During Fiscal Year 1990, Norfolk Naval Base recycled 14.7 million pounds of solid waste consisting of paper, cardboard, aluminum cans, and scrap metal. Some recyclables are source separated in curbside programs; others, such as cardboard are either separated and collected at source or culled from the general solid waste stream at the Norfolk Transfer Station (Figure 21), which serves as a central waste collection point and a rudimentary materials recovery facility for the base recycling program.

With guidance from the participating recycled plastic manufacturers, DTRC requested Norfolk to collect rigid plastic containers and film plastics for the pilot program. Norfolk Naval Base collected several bales of LDPE shrink-wrap from various supply and staging organizations both pierside and shipboard. The majority of plastic collected by Norfolk Naval

Figure 21: Norfolk Naval Base Transfer Station—recovering plastic on sort floor

Base was HDPE small-mouth containers, plastic bread trays, and miscellaneous 5-gallon containers. The greatest item by number was containers of Aqueous Film Forming Foam (AFFF), a fire fighting substance used aboard Navy ships. All containers were empty and some had been rinsed clean. Figure 22 shows these plastics baled and ready for shipment. Table 3 lists the types of material that were contained in the high density polyethylene containers collected at Norfolk.

Table 3: High-Density Polyethylene Containers Separated at the Norfolk Naval Base Materials Transfer Station

AFFF	Potassium hydroxide
Floor wax finisher	Latex paint
Anti-freeze	Oil-based paint
Imported olives	Degreaser
Detergent	Bleach
Disinfectant/fungicide	Terrazzo sealer

Figure 22: Baled Norfolk Navy shipboard plastics

Recycling Shipboard-Generated Plastic Waste at the Manufacturers' Facilities

Rivenite Corporation

In September 1990, DTRC shipped Rivenite Corporation 7000 pounds of Navy shipboard-generated plastic waste from the Norfolk Naval Base. All of this waste was plastic film because Rivenite had stated a preference for this type once the difficulties associated with collecting food-contaminated plastics became apparent. Rivenite found the Navy plastic film similar to LDPE industrial plastic film they normally processed. Rivenite encountered no difficulties or abnormalities while processing the Navy's waste.

Rivenite produced 20 picnic tables and 32 carstops from the 7000 pounds of Navy plastic waste. Figures 23 and 24 show a sample picnic table and carstop made from Navy recycled plastic waste. Figure 25 shows a cross-section of a profile manufactured from Navy plastic waste. The relatively coarse grain is due to the size of the sawdust particles used in this extru-

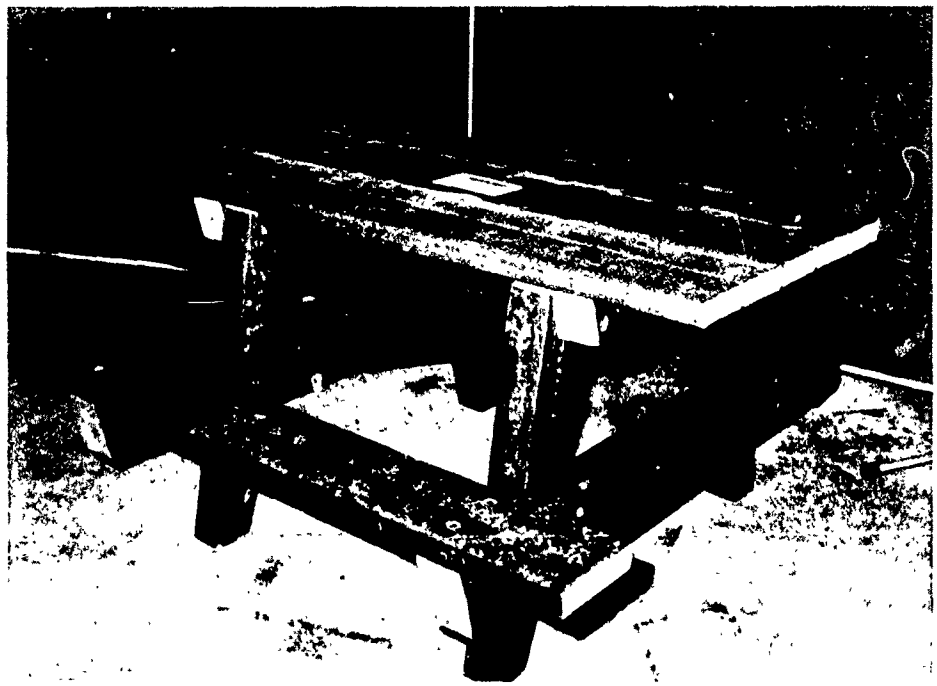

Figure 23: Rivenite Corporation—
Rivenite® picnic table made from Navy plastic waste

Figure 24: Rivenite Corporation—
Rivenite® carstop made from Navy plastic waste

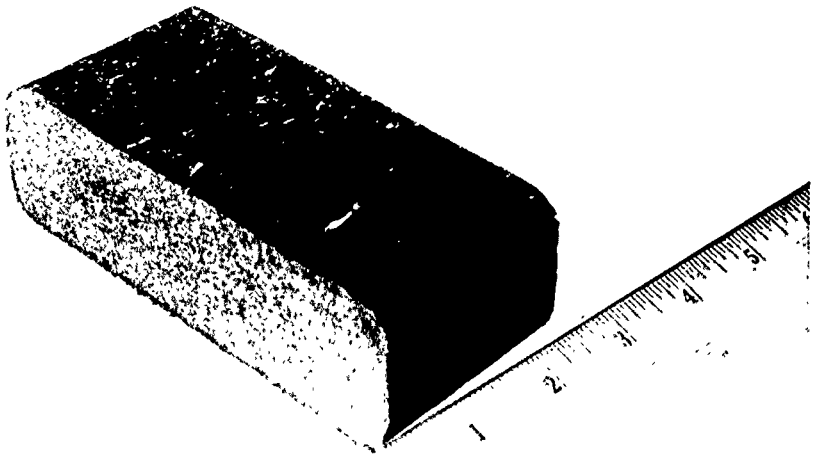

Figure 25: Cross section of Rivenite® made from Navy plastic waste

sion run. The lumber manufactured by Rivenite had varying texture due to changes in the size of sawdust particles. Rivenite obtains the sawdust for their process from local milling companies. (Many Navy facilities recycle wood products, such as irreparable shipping pallets. Although not within the scope of this program, an interesting possibility would be to process scrap pallets from Navy activities into sawdust for Rivenite®.)

Although Rivenite preferred processing waste from the Norfolk Naval Base, it is possible that the firm could have processed a large proportion of *Lexington*'s wastes once sorted. However, CSWS and DTRC chose to route that waste to National Waste Technologies, Inc. because they had the facilities for performing a final sort prior to processing.

Hammer's Plastic Recycling Corp.

In October 1990, DTRC shipped Hammer's 5000 pounds of HDPE containers from Norfolk Naval Base. These bales consisted mostly of 55 gallon AFFF containers although there were also small quantities of the con-

Figure 26: Baled Navy plastic received by Hammer's Plastic Recycling Corp.

tainers listed in Table 3. Hammer's found substantial amount of mud caked onto the bales resulting from outside storage of the bales in Norfolk (see Figure 26). Although Hammer's had not requested inside storage, they normally would have rejected the material for not meeting their standards. However, Hammer's did agree to process the waste for purposes of the demonstration and no known problems resulted. Although there was considerable concern that these bales would also contain excessive moisture, when they were broken apart for pre-processing, this was not the case. No additional drying beyond that provided by the grinder was necessary. Although CSWS and Navy representatives witnessed production of

some end-pieces for Navy park benches, the details of Hammer's proprietary processes were not documented.

Hammer's expressed concern at the predominance of dark blue and black containers in the shipment because dark colored feedstock creates a dark colored end product. While clear or light colored feedstock can be pigmented for certain colors, the reverse is not possible. Dark colored profiles absorb more ultra-violet rays and consequently get hotter than lighter ones. Therefore, Hammer's produces seats for their park bench from light or clear stock that is pigmented a uniform gray color.

For this reason, Norfolk plastics were separated into light and dark fractions. The light fraction was mixed with approximately 22% LDPE and 21% polyester industrial scrap to improve the surface finish of the final product. In addition, a color concentrate was also added to the mix to provide color consistency.

During December 1990 and January 1991, Hammer's produced 47 four-foot park benches for the Navy project. An example is shown in Figure 27.

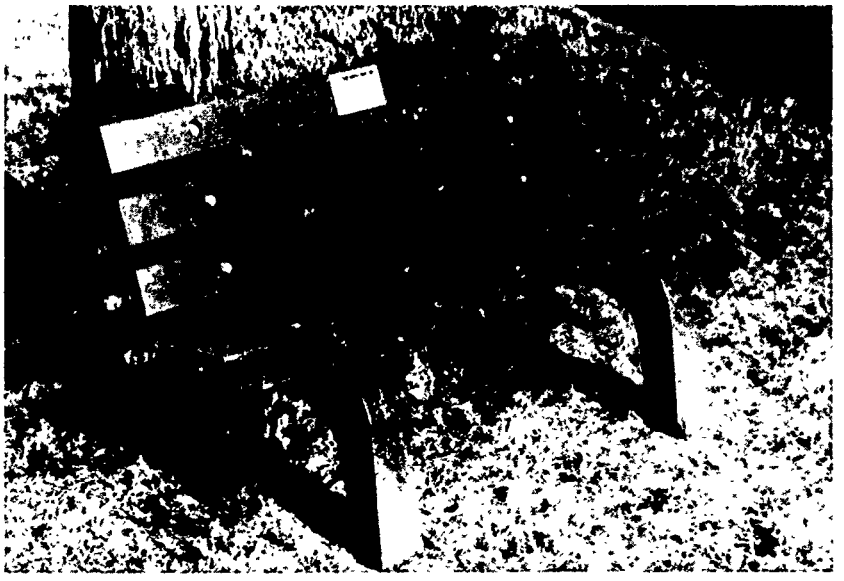

Figure 27: Hammer's Recycling Corp.— park bench manufactured from Navy plastic

National Waste Technologies, Inc.

In November 1990, DTRC shipped seventeen bales (11,800 pounds) of Navy plastics to NWT for processing. Fourteen bales were HDPE similar in composition to those received by Hammer's. Two bales consisted of LDPE film. DTRC also shipped the one 1200 pound bale of mixed plastic wastes from *Lexington* that had been pre-sorted at the Escambia County landfill. This bale consisted of polystyrene foam cups, bread bags, bottles, disposable razors, latex gloves, shampoo bottles, and other miscellaneous items listed in Table 2. NWT found the waste composition of Navy comparable to the majority of plastic materials they processed.

Some of the waste required special handling. The AFFF containers were too large for the shredder and had to be cut into quarters before they were conveyed to the shredder. Figure 28 shows the residue found in one of the unwashed containers. This residue proved unharmful to the process. NWT physically removed some items prior to processing (including two polyurethane foam mattresses). A small amount of paper also was removed. A large metal window crank, hidden between layers of film in one bale, was inadvertently fed to the densifier, damaging the blades

Figure 28: National Waste Technologies, Inc.— residual liquid in split AFFF container

Figure 29: National Waste Technologies, Inc.— removal of non-recyclables at conveyor line

beyond repair. NWT's magnetic metal separator removed 6.4 pounds of metal contaminants from the 11,800 pounds of Navy plastic waste, a very small percentage according to their experience. Figure 29 shows non-recyclables and film plastics being separated from the rigid plastics on the conveyor system prior to shredding.

NWT pre-processed the film plastics and hard plastics by densifying the film fraction and shredding and grinding the rigid plastic fraction. NWT tested the 79%/21% "ideal" ratio on a sample of the Navy's waste. The blend proved excellent feedstock for the NWT ET-1 extrusion system, and the entire Navy waste batch was processed in this ratio. Due to the high percentage of dark-colored containers, NWT chose to produce dark-colored benches given the Navy's desire to have benches made 100% from Navy shipboard plastic. Other than the densifier damage, NWT considered the processing of the Navy waste routine and without incident.

NWT does not have the capability to manufacture the end-pieces for its park benches and instead, purchases these from another vendor who manufactures them from industrial plastic scrap. The NWT park bench

Figure 30: National Waste Technologies, Inc.— park bench manufactured from Navy plastic

shown in Figure 30 is made from Navy plastic (slats) and post-consumer waste (end-pieces). NWT produced a total of 87 five foot park benches for this program.

Disposition of Recycled Plastic Products from the Pilot Program

All the recycled plastic products were shipped to DTRC in December 1990 and January 1991 for inspection. DTRC mounted plaques (shown in Figure 31) on each product denoting the origin of the plastic material recycled into the product. At the time of writing of this report, park benches, picnic tables and carstops have been distributed back to *Lexington;* Pensacola Naval Air Station; Naval Supply Center, Pensacola; Chief of Naval Education and Training (CNET); Norfolk Naval Station; Morale, Recreation and Welfare (MWR) Training Center at Patuxent River Naval Air Station; and the United States Naval Academy. Plans are underway to distribute additional items to other bases and facilities to assist in promotion of other Navy recycling programs.

Figure 31: Plaque on park bench

Discussion

Quality of Navy Shipboard-Generated Plastic Wastes

The plastic lumber manufacturers participating in this program were pleased overall with the relatively high quality of the plastic recovered by the Navy for recycling. Although exact figures on amounts of actual contaminants in the plastic waste delivered to the manufacturers were not obtained, they are extremely low.

This is attributed to the fact that all the Navy waste plastic had been sorted *at least once* before it was delivered to the manufacturer. In the case of *Lexington* plastic waste, the ship's crew provided the initial sort into nonfood-contaminated and food-contaminated plastic fractions. Then the nonfood-contaminated plastic was sorted into recyclable and non-recyclable fractions at the Escambia County MRF. The recyclable portion was shipped to NWT where it underwent a final sort into rigid, film, and non-recyclable fractions. On the other hand, the wastes from the Norfolk Naval Base had been culled from the general shipboard solid waste stream. Large items, previously known to be recyclable (such as AFFF con-

tainers), were sorted from the waste stream at-large with no regard for any previous sorting by ships' crews into plastic and non-plastic fractions. These plastics were, in turn, divided into rigid (HDPE) and film (mostly LDPE) portions and processed accordingly at each manufacturer. In order to recover shipboard-generated plastics directly from Norfolk area ships, an extensive pre-sort similar to the one at the Escambia County MRF would likely be required.

Food-Contaminated Shipboard Plastic Waste

At the onset of this program, DTRC optimistically endeavored to collect and recycle food-contaminated wastes from *Lexington*. The plastic wastes collected during the first few at-sea periods had to be landfilled because food products on the waste were partially decomposed by the time the ship reached port. Plastic wastes were stored in trash storage rooms without cooling facilities for up to seven days. It became obvious that in spite of *Lexington's* efforts to remove excess food residues, this portion of the waste stream would be difficult to store.

Once attempts to store food-contaminated plastics were abandoned, the challenge then became to ensure that the so-called "nonfood-contaminated plastics" were just that. On Navy ships, food-contaminated plastic waste in the form of candy wrappers, polystyrene hot meal trays, yogurt cups and other food packaging from items obtained from ship's stores or vending machines often makes it way into "plastics only" containers located in work and berthing spaces. During the Escambia MRF sort of the nonfood-contaminated plastic waste, many items such as potato chip bags, coffee creamer individual servers and candy wrappers were counted. Even small amounts of food residue can contaminate collected wastes and thus create odor and sanitation problems.

In the United States today a number of plastic recycling programs are targeting food-contaminated polystyrene foodservice items, including utensils, plates, trays, bowls and cups. The National Polystyrene Recycling Company is setting up reclamation facilities around the country which process food-contaminated plastic from fast food restaurants, schools, institutional cafeterias, and other generators, with a goal of 250 million pounds of polystyrene by 1995. This equals 25 percent of the polystyrene produced in the United States for food service and packaging applications each year. Handling and reclamation technologies for food-contaminated plastics

are being optimized in these private sector programs. These technologies will be of use to the Navy for recycling shipboard-generated plastic waste.

Non-Recyclable Plastic Waste from *Lexington*

Of the 2000 pounds of nonfood-contaminated plastic waste obtained from *Lexington* during the final at-sea period of the pilot program, only 1200 pounds were considered recyclable.

The non-recyclable materials sorted at Escambia County MRF fall into two general categories: (1) plastic or composite "non-recyclables" listed in Table 4 and (2) non-plastic, non-recyclables listed in Table 5. Figures 16 through 20 show many of these items. Representatives of CSWS and DTRC rejected these items on the basis of assumed incompatibility with the recycling processing equipment. Some items, such as nylon line, are synthetic and can be melted and reformed in the extrusion process, however they are likely to cause problems with shredding and grinding equipment in the pre-processing stage. Similarly, large quantities of plastic coated electrical wire are likely to jam the cutting mechanisms of some shredders.

Table 4: Non-Recyclable Plastic and Composite Items Collected from *Lexington* Waste at Escambia County MRF
Nylon-reinforced paper rags
Foam mattresses (with cotton ticking covers)
Emergency lamps
Non-infectious medical waste packaging
Life jacket (with metal air cartridge still attached)
Hair dryer with plastic body and plastic-coated wire and plug
Rolls of duct tape, vinyl tape, strapping tape
Mylar balloon
Feminine hygiene products
Polaroid film (with paper backing)
Metalized plastic dryer hose
Pipe insulation
Plastic-coated wire and electrical cable
Nylon line (rope)
Waterproof ink markers
Cigarette butts
Vinyl dress shoes
Coffee creamer packets with plastic liners
Glass soda can (with plastic lid)
Flight deck goggles
Fiberglass insulation
Plastic-encased electronic parts
Linoleum tiles
Fan belt

Table 5: Non-Recyclable, Non-Plastic Items Collected from *Lexington* Waste at Escambia County MRF

Paper rags
Copper pipe
Steel mirrors
Light bulbs
Bathroom tissue
Rubber hose
Rubber tire inner tube
Steel-toed rubber roots
Metal coat hangers
Bag of painting clothes
Hemp
Rags
Clothes, socks
Cardboard
Paper
Soap
Aluminum cans
Cork gasket material
Padlocks
Batteries

Other items, such as foam mattresses (still covered with cotton ticking) and plastic-encased emergency lamps could conceivably be shredded to processible size, but this introduces non-plastic contaminants into the extruded product and decreases its quality. While items such as plastic-lined coffee creamer packages, wax-coated paper cups and cigarette butts occurring incidentally prove no major problem, processing the large quantities found in *Lexington*'s waste would result in an inferior final product.

The composite materials processed by NWT were shredded and conveyed under a rotating magnet in order to remove the ferrous metals. Some items, such as the fiber-reinforced hose shown in Figure 17, contain more metal than synthetic material and would unnecessarily tax shredding and magnetic separation equipment.

During the *Lexington* pilot recycling program, DTRC requested that *Lexington* separate plastics from non-plastics in accordance with the Fleet policy. Since this policy is based on the MARPOL definition of plastics, Navy ships are required to

retain onboard for discharge ashore any object that is all *or part* plastic. Table 4 is a partial list of "plastic/composite non-recyclable" items.

Items such as latex gloves, rubber tire inner tubes and wax-lined paper cups occupy a "gray area." Although wax and rubber are "natural polymers" and thus may be exempt from the MARPOL definition, it is rare to find items made from the raw material without some additional polymizer introduced during manufacturing. These items are often discarded into "plastics only" containers and rightly so, since from a MARPOL perspective, it is better to err on the side of caution and keep all such questionable items out of the ocean.

In comparison to aggressive and comprehensive household collection programs that target mixed plastic waste, the Navy requirement to include all plastic or plastic-containing items at time of source separation makes the Navy's waste even more "mixed." This policy introduces a large number of contaminants that pose problems to most recyclers, and requires an additional level of sorting prior to processing.

The second category of non-recyclables found in the Escambia County *Lexington* waste sort were non-plastic items. Table 5 lists some of these items. Table 6 lists additional plastic containers that had some residual contents. Small quantities of these residual materials might be processible by recyclers but would likely pose risks to equipment and personnel and would reduce the quality of the resultant end product.

Table 6: Non-Recyclable Material Containers

Chemical light sticks
Aerosol spray cans with plastic tips
Fingernail polish
Fingernail cleaner
Two-part epoxy glue
Copier ink cartridge
Painting materials

The authors estimate that approximately 50% of the non-plastic, non-recyclable waste (or approximately 400 of the 800 pounds) was paper and rags. During the course of the program, *Lexington* switched from nylon-reinforced paper rags (considered plastic because of the reinforcement) to an all-paper rag, and it was difficult to differentiate between the

different rag types. Also, there was a notable quantity of aluminum cans in the waste, in spite of the fact that *Lexington* had for some time been recycling aluminum cans through a separate MWR program. The high percentage of non-plastic and composite items in the waste indicates the difficulty of the source separation task aboard ship.

Impact of Plastic Waste Quality on Final Product

While it may be eventually possible to recover all Navy plastic wastes, the technology for producing recycled plastic lumber is just beginning to evolve. The American Society for Testing and Materials (ASTM) is starting to develop standards for evaluating plastic lumber products. Although at least eight states and a number of private enterprises are conducting testing programs of plastic lumber products, only limited information is currently available.

DTRC, CSWS, and NWT conducted a trial processing run in August 1990 to determine if there was an "acceptable" level of contamination in the waste stream that recyclers could process. One bale was processed that had been sorted by *Lexington* in accordance with Fleet guidance to include all plastic or plastic-containing items. Although NWT re-sorted and removed as much non-plastic as possible, a large percentage of moisture from food and a large percentage of paper contamination remained. Although NWT was able to produce a 10 foot sample length from this waste, the cross-section contained numerous voids and cavities (see Figure 32).

Over the last several years, universities, testing laboratories and manufacturers have performed tests to determine the physical properties and strength characteristics of profile extrusions produced from post-consumer plastics waste and the effects of reinforcing additives such as glass fiber. Some of the key areas that remain to be studied in detail include aging characteristics of plastic lumber, particularly with regards to weatherability and longevity. Although many manufacturers claim that plastic lumber is superior to wood, the industry has limited data available, having emerged so recently.

Figure 32: Cross-section of lumber made from highly-contaminated Navy waste plastic

Shipboard Source Separation and Collection Methods on *Lexington*

It was apparent from the Escambia County MRF sort of *Lexington*'s waste that the ship's crew had difficulty separating plastic and non-plastic. At the start of the program, *Lexington* had not formalized plastic waste source separation. Many sailors hung plastic bags from wall fixtures in office and berthing spaces to collect plastic wastes, but none of these practices was consistent throughout the ship. As the pilot program evolved, *Lexington* made a number of changes to help institutionalize the source separation of plastics. Indeed, improvements were made in reducing the amount of non-plastic contamination in the waste as sailors became more aware of the plastics program and were provided convenient ways to collect plastics.

Crew Education and Awareness

During the five months of the pilot program, progress was made to educate *Lexington*'s crew on the purpose and benefits of retaining plastics shipboard for the recycling program. *Lexington*'s officers

publicized the plastics program using the closed-circuit TV system and notices in the Plan of the Day (a daily schedule for shipboard events). Divisional officers conducted spot checks of their spaces for adherence to plastics collection policy. Officers and master-at-arms (military police) occasionally monitored the disposal of sinkable solid wastes off the fantail (permissible Navy practice outside of 25 nautical miles), checking for inadvertent disposal of plastic items. Announcements were made over the public address system, reminding the crew to separate their plastic wastes from non-plastic wastes.

However, there was no truly effective means to assess the effectiveness of the separation process and provide feedback to the crew on a real-time basis. *Lexington* used both clear and dark-colored plastic garbage bags for collecting plastic wastes. Midway through the program, DTRC requested that *Lexington* use only clear plastic bags to facilitate inspection and compliance with source separation. The ship attempted to comply but experienced some difficulty effecting a 100% change from colored to clear bags in the short time frame required. Even with clear plastic bags, it was impossible to inspect every plastic bag and completely check for non-plastic items.

The first priority of the program on *Lexington* was to fully comply with Fleet policy to retain all (MARPOL defined) plastic wastes. The second priority was to collect the plastics for recycling. As a result, *Lexington* did a much better job of collecting plastics while at sea and was less rigorous when in port, due to the convenience of portside disposal. Lack of consistency between at-sea and in-port operations led to some confusion about what was really required.

"Plastics Only" Containers

Lexington obtained 1100 waste receptacles of different sizes, ranging from 10 gallon wastebaskets to 45 gallon trash cans before the final at-sea period. These were painted "environmental green," with red letters denoting "Plastics Only" painted on the side. Figure 33 shows the placement of this can next to a second trash for all other solid waste. These containers provided constant reinforcement for the crew to

source separate plastic wastes. Most important, sailors found it easier and more convenient to separate the waste into plastic and non-plastic fractions, when cans were placed side-by-side.

Pierside "plastics only" dumpster

A "plastics only" dumpster was placed pierside for disposal of plastic wastes when the ship was in port. This container was used to collect all plastic wastes and transport them to Pensacola Waste Paper, Inc. for baling prior to shipment to the recyclers. Most of the time, this container was unguarded and uncovered. There was more than one occasion when obvious, non-plastic items were found in the dumpster. Without adequate control over this container, it was repeatedly fair game for all-purpose refuse disposal from sources both aboard ship and ashore.

Plastic Recycling Program Economics

Because relatively small quantities of plastic materials were recovered during the pilot program, it was not possible to optimize the costs incurred for handling, sorting, transporta-

Figure 33: "Plastics Only" container aboard Lexington

tion, and processing. The objective of the demonstration was to demonstrate technical feasibility, not create an economically viable recycling system based on economies of scale. Therefore, program costs incurred by CSWS and the Navy were not representative of those for full-scale recycling programs and cannot be used as a basis for extrapolation. However, expense categories listed below must be considered when planning a full-scale, "closed loop" recycling program, where Navy plastic waste is recycled into end-products the Navy can procure.

- Purchase of appropriate on-board collection bins for plastic waste collection and storage
- Purchase/lease of centralized pierside recycling container for pierside collection of ship's plastic wastes
- Labor, facility, and location for sorting to remove contaminants
- Disposal costs for non-recyclable items
- Baling of plastic wastes before/after sorting
- Transportation of plastic wastes to recycler/manufacturer
- Purchase price of recycled plastic product
- Return transportation of recycled products back to Navy facility

In a full-scale recycling program, economies of scale drive most decisions and can be used to improve program efficiency and cost. Containers and other capital expenditures for collection and handling of plastic materials can be amortized over the effective life of the equipment. Other capital equipment, such as baling or conveyor systems used for shoreside sorting, would likely be used for other recovered materials, such as paper and cardboard. Combining the plastic derived from shipboard sources with waste from shoreside activities may prove essential to developing viable markets for shipboard-generated plastic wastes.

Likewise, commercial transport of baled plastic is usually by 30,000 to 45,000 pound tractor trailer-sized loads for cost effectiveness. Typical charges for long distance transport of trailer sized loads of plastic in today's prices are about $20 per ton of material for every 200 miles traveled.

Costs associated with the separation of plastic by a MRF sorting operation have not been widely documented. Based on information collected during a recent CSWS telephone survey of recycling firms involved in the separation of mixed

plastic bottles, the cost of sorting plastic bottles is estimated at approximately 3 cents per pound of plastic separated. This cost is based on an assumption that a worker can sort 400 to 500 pounds of mixed plastic bottles per hour. This estimate includes the costs of labor, equipment depreciation, land, insurance, utilities, materials, maintenance, rent, and other overhead expenses. It is provided to give an order of magnitude of cost for sorting but is not necessarily what the Navy could expect when sorting plastics from a mixed stream.

The three lumber manufacturers all required that minimum quality standards be met for the plastic they accepted in this program: no food-contaminated, composite or non-plastic items. In addition, Hammer's was not satisfied with the color of incoming plastic waste, while both Hammer's and Rivenite preferred to process only specific types of plastic resins (primarily HDPE and LDPE) to suit each firm's respective operating procedures. Of the three firms in the pilot program, only NWT was willing to process the entire stream of sorted, nonfood-contaminated Navy plastics without regard for color or resin mix.

Inasmuch as these factors affect the costs of sorting, the following levels of sorting may be required for processing Navy shipboard plastic wastes:

- removal of food-contaminated plastic waste
- removal of composite plastic items
- removal of non-plastic contaminants
- separation by resin type
- separation by color

These sorting options parallel those currently conducted by facilities handling household recyclables generated by communities across the country. These levels of sorting can be accomplished at various stages between shipboard collection, shoreside sorting and at a manufacturer's facility. The economic and logistic costs associated with each choice must be analyzed.

In today's market, recyclers do not usually reimburse suppliers of mixed or commingled plastic waste. On the other hand, cleaner streams of plastic bottles, in todays' market, have monetary value. In some instances, transportation costs are paid by the market and in all cases the quality of the plastic waste is a driving factor. Thus, the only constant benefit derived by mixed waste plastic feedstock suppliers (the Navy in this instance) is the avoided disposal fees that would have been incurred had the plastic waste been disposed of at a local

landfill or incinerator. Today, these fees range from $20 to $200 per ton, depending on local solid waste management options, providing significant incentive to businesses and institutions to recover plastic waste materials when practical.

Plastic lumber manufacturers typically process plastic waste materials that are considered unsatisfactory for reprocessing into higher-value end products such as bottles and carpet backing. For these, resin type, uniformity, and quality are more important. However, Navy shipboard-generated plastic materials that can be readily separated by resin type and kept free from contamination during collection and storage are already in demand (i.e. AFFF containers, sonobuoy casings, HDPE bread trays, and shrink wrap). For example, markets for post-consumer plastic paid $100 to $200 per ton for clean, separated HDPE materials during 1990.

In a closed loop recycling scenario, costs are also avoided in the buy-back of recycled products at discount prices. For example, Hammer's Plastic Recycling currently has a "turn-key" contract with the Chicago Park District. Under the terms of this contract, Hammer's is required to accept Chicago's curbside-collected, post-consumer plastic for manufacture of plastic park benches and other products used exclusively in Chicago's public parks. The Chicago Park District, in turn, purchases these products at discount prices.

Even though initial purchase price of items made from plastic lumber may not be competitive with those of non-plastic counterparts, life-cycle costs are usually reduced when maintenance and replacement costs are considered. For example, park benches made from recycled plastic require virtually no maintenance. Landscape timbers made from recycled plastics often come with "lifetime" guarantees, compared with no guarantees for pressure-treated wood. Manufacturers assert that marine pilings made from recycled plastic are virtually 100% resistant to rot and marine borers. Thus, the persistent quality of plastic, considered an environmental problem in the form of ocean and beach litter, becomes an advantage as long term applications are discovered.

Plastics Recycling Industry Trends

A number of consumer surveys indicate that Americans are willing to purchase "environmentally friendly" products. Consumer product manufactures have embraced the concept of "green marketing" to match the needs of American households. What better way to express a company's concern

for the environment than to package their goods in materials made from recycled plastic? Recently, consumer-goods giants Procter and Gamble , Lever Brothers, Coca Cola, and Pepsi Cola Company have all announced plans to manufacture product containers with some percentage of post-consumer recycled plastics. These programs will require strong and steady streams of waste plastic. Markets for recycled plastic resin will certainly improve with time.

At present, more than 29 states have adopted comprehensive mandatory or voluntary recycling goals to be reached between now and the year 2005. These recycling goals range between 20% and 56% of each state's total waste stream. To facilitate the recycling of plastics specifically, 27 states now require that plastic bottles and containers carry a code specifying the type of plastic from which the container is made. This follows the packaging industry's adoption of The Society of the Plastics Industry's (SPI) Voluntary Plastic Container Coding System for plastic bottles. The SPI program was developed and adopted by the plastics industry to help recyclers in identifying and sorting plastic bottles by resin type.

Reclaimers of post-consumer plastics are establishing businesses at an unprecedented rate. All three manufacturers participating in the Navy pilot program have plans or are already in the process of expanding to other geographic or nationwide locations. Hammer's was recently acquired by an investor group that intends to strategically expand the firm's production operations to twelve locations across the United States. NWT has publicly announced the purchase of thirty ET-1 machines over the next five years to be placed strategically around the United States based on availability of plastic wastes for feedstock. The creation of joint ventures between the nation's largest waste haulers and plastics producers and recyclers demonstrate that plastics recycling has become big business in the United States.

In summary, the plastics recycling industry is in the midst of an expansion driven by the environmental consciousness of the nation. As a result, market prospects for the Navy's recyclable plastic materials are bright and are expected to improve with time. At the same time, as more and more shoreside programs come into place, sailors on Navy ships will increasingly accept the need to collect plastic wastes for recycling.

CONCLUSIONS

The following conclusions from this pilot program are made regarding the technical feasibility of recycling Navy shipboard-generated plastic waste.

- Navy shipboard-generated plastic wastes *can* be recycled, although certain categories of plastic waste are easier to handle and more marketable than others.

- Navy shipboard-generated plastics must undergo some level of sorting before being recycled. During this program, plastic waste was sorted at different stages by removal of food-contaminated plastic waste, removal of composite plastic items, removal of non-plastic contaminants, and separation by resin type and color. This could only effectively be accomplished by using facilities and personnel at shoreside materials separation facilities (e.g., Escambia County MRF and Norfolk Naval Base Transfer Station).

- Adherence to the Navy's policy to source separate plastic waste according to MARPOL definitions results in collection of significant quantities of contamination by composite materials. Many of these items are unacceptable to plastic recyclers, although manufacturers of recycled plastic lumber may accept and sort this mixed waste stream prior to processing. Shredding and grinding equipment can be damaged while pre-processing some of these items.

- The plastics recycling industry lacks clearly defined quality standards for plastic waste feedstock. Each of the three manufacturers of plastic lumber in this program had slightly different requirements for processing waste plastics.

- Navy ships generate high value plastic wastes in the form of HDPE plastic containers and LDPE films. If these materials are separated by type and color and stored away from excessive moisture and dirt, they can command premium prices comparable to wastes from more traditional curbside programs.

- Food-contaminated plastic wastes pose special problems in shipboard and shoreside handling. Unless all food particles are removed and wastes are thoroughly washed, collection and long term storage of these wastes will likely create health and sanitation problems as food products decompose and odors result. The requirement for additional manpower and special equipment may discourage recycling of this category

of Navy shipboard-generated wastes at this point in time. However, handling and reclamation technologies that can be of use to the Navy are being optimized in private sector food-contaminated plastic recycling programs.

- Like the Navy's "plastics at sea" program (that is eliminating discharge of plastics into the ocean), the shipboard recycling program must have management support and be institutionalized in order to be successful.

- Procedures and equipment, like specially marked waste receptacles, that make source separation more convenient for the sailor promote maximum participation and minimize non-plastic contamination.

- Participants must be provided feedback on the quality of their source separation methods if shipboard source separation is to be relied upon for removal of non-recyclable contaminants.

- As in all shoreside recycling programs, education and feedback are essential to the process of changing habits regarding disposal of wastes. Instruction as to what is and isn't plastic may be required. Each individual should be reached and made aware of the importance of her or his participation in the program.

Recommendations

The following recommendations are offered at the conclusion of this pilot program.

- **Develop a Navy-wide strategy** for the recovery of Navy shipboard-generated plastic wastes. The Navy should identify procedures for collection and handling recoverable wastes while aboard ship that are consistent for at-sea and in-port periods. Conduct plastics recovery operations aboard several typical Naval vessels in order to determine the most appropriate methods of implementing the Navy-wide plastics recovery program. Conduct analyses of economies of scale that can be achieved in large scale programs that are organized by geographic area and/or by combining with existing Navy and local municipal shoreside programs. Evaluate the feasibility of utilizing shoreside MRF's for sorting shipboard-generated plastic wastes at major Navy ports.

- **Create or adopt a theme and logo** for the Navy plastics recycling program. The theme and logo should be consistent with each other, artfully designed and contain an appropriate message to represent the program. Design a recycling brochure to highlight keys points of the program.

- **Provide Navy personnel sufficient information and training** concerning shipboard recycling programs to improve the quality of materials collected. This training should be geared towards positive feedback for changing waste disposal habits and should include information on the advantages of the recycling program, how the plastics-at-sea program is integrated with shoreside recycling of shipboard plastic wastes, clear definitions of what plastics can be recycled, and, if appropriate, how to prepare these materials for recycling and procedures for collecting and storing materials prior to collection portside.

  For maximum effectiveness, shipboard programs must include ample opportunity for personal attention, instruction and question-answering. The purpose of the educational program is to instill the awareness that individual participation makes a difference and show how in the bigger picture recycling makes a difference.

- **Recognize and reward successful shipboard recycling programs.** Recognition can be provided to outstanding individuals on a single ship or to the ships themselves.

- **Coordinate shipboard recycling activities through an assigned shipboard recycling coordinator.** The recycling coordinator should be given the authority to implement and enforce the ship's plastic recovery program. The recycling coordinator should be responsible for all activities related to recycling, including training, collection, storage, and offloading as well as coordination with shoreside recycling functions.

- **Adopt standard shipboard collection containers for all Navy ships** clearly marked for the recycling program in order to distinguish from other general refuse containers.

- **Adopt standard and consistent shipboard procedures for at-sea and in-port source separation** of plastic wastes that promotes plastic waste collection and minimizes confusion among participants.

- **Use clear garbage bags** on all Navy ships in order to allow for the inspection of bag contents for recoverable plastics.

- **Separate food-contaminated plastic wastes** from nonfood-contaminated wastes to minimize contamination of and maximize recovery of recoverable fraction of Navy plastics.

- **Provide mixed Navy plastic waste to plastic lumber manufacturers,** but recognize and capitalize on the fact that other markets exist for certain higher quality Navy plastic wastes.

- **Stay abreast of available markets** for the sale of Navy shipboard-generated plastics, especially HDPE containers and LDPE film packaging. Due to the increased demand for recycled plastic, new markets continue to develop for recyclable plastic feedstock. Current market activity almost guarantees buyers for certain portions of the Navy's HDPE and LDPE.

- **Procure recycled plastic products for Navy use.** While shipboard recycling programs are being planned, the Navy can procure recycled plastic products such as landscape timbers, marine decking materials and pilings, park benches and picnic tables for use at Navy bases.

- **Investigate new uses for recycled products for Navy applications (e.g., plastic pilings).** Encourage Navy R&D and testing of recycled plastic products for shipboard and shoreside applications.

SUMMARY

David Taylor Research Center and The Council for Solid Waste Solutions began this pilot program with many unresolved questions concerning the feasibility of recycling the Navy's shipboard-generated plastic waste stream. However, end-products with the potential for future procurement by the Navy *were* successfully manufactured from Navy shipboard-generated plastic waste.

Information gained from the program will assist future development of Navy recycling programs and clearly presents a recycling option to dealing with MARPOL plastics collected and retained by Navy ships. In light of the rapid growth of the plastics recycling industry nationally, the potential for recycling of shipboard-generated plastic waste is very optimistic.

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From April 1990 through January 1991, the David Taylor Research Center undertook a joint research project with the Council for Solid Waste Solutions to explore the feasibility of recycling Navy shipboard-generated plastic wastes. Normally, plastic wastes are source separated aboard Navy ships and retained for shoreside disposal in accordance with new fleet requirements implementing MARPOL Annex V that prohibits the discharge of plastics at sea.

Over 23,000 pounds of shipboard plastic wastes from USS *Lexington* (AVT 16) and ships from the Norfolk Naval Base were recycled into park benches, picnic tables and carstops that have been distributed back to the Navy bases for use.

Navy shipboard plastics must undergo sorting prior to recycling because Navy plastic waste, collected in accordance with MARPOL Annex V definition of plastic, contains large quantities of composite plastic items (e.g., plastic/paper) that are not easily recyclable. Recycling food-contaminated plastics is not practical due to sanitation problems encountered during handling. However, certain items have good resale value if separated by resin type and color (e.g., sonobouy casings, hard plastic containers, packaging films).

Education, feedback, and command support for shipboard recycling programs are required to ensure maximum participation and to minimize contamination with non-plastic items. Specially marked "plastics only" containers increase convenience and effectiveness of the recycling program.

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